

1 – B. Highlights of Soybean Rust Research at the Asian Vegetable Research and Development Center

Glen L. Hartman, Crop Protection Research Unit, USDA, Agricultural Research Service and Department of Crop Sciences, University of Illinois at Urbana-Champaign, Urbana, IL¹

Soybean rust is one of the major diseases of soybeans in Asia and significant yield losses occur from most soybean-producing countries throughout Asia. Nearly all tropical and subtropical countries have reported the occurrence of soybean rust where it is endemic (20). In Taiwan, rust can cause severe losses to soybeans not protected by fungicides and in some locations, like Hualien county, rust is a limiting factor to soybean production in the spring season.

Because of the paucity of information about soybean rust in the Eastern Hemisphere and the potential danger to soybean production in the continental U.S., the U.S. Department of Agriculture, Plant Disease Research Laboratory and the Asian Vegetable Research and Development Center (AVRDC), started a cooperative project in 1978 to study the epidemiology of soybean rust. This cooperative project continued until 1982 (22) and the research on soybean rust continued at AVRDC until 1992. In this report, I have highlighted some of the data primarily collected at AVRDC to discuss soybean rust research. Much of this research is reviewed in more detail elsewhere (12, 22, 30).

Along with research on soybean rust, AVRDC also trained and disseminated information on soybean rust. The *Soybean Rust Newsletter* was first published in 1977 with the last issue (Vol. 9) published in 1989. A bibliography (3) and an updated annotated bibliography with a review on soybean rust was published with 480 abstracts (4). In addition, about

10 trainees were trained at AVRDC specifically on aspects of soybean rust research. The current status of the AVRDC grain soybean program has moved to Thailand and it is uncertain whether there is interest or funds to continue research on soybean rust. Although C. Yang, Director of the AVRDC Thailand program, recently attended a workshop on soybean rust in China (32). In addition, AVRDC has been involved in establishing an Asian network with FAO which would have a subcomponent on soybean rust research (1). Other Asian countries, where AVRDC has had contact through years, have in some cases continued research on rust. The national program in Thailand has been conducting research on soybean rust with an active breeding program for the past 10 years (17, 18). In Indonesia, rust is considered the most important soybean disease and is widespread, occurring in both the rainy and dry seasons. Research activities in Indonesia include improving host resistance, fungicide testing, persistency of urediniospores in the field, management of rust through cultural practices, and studies on spore dissemination (Hardaningsih, personal communication). Other countries, like South Korea, do not conduct research on soy-bean rust even though it is present (G. B. Lee, personal communication). In Australia, where rust has been intensively studied in the past, funds are limited for research, and their work now is restricted to screening backcross populations from crosses of soybean and *G. tomentella* (J. J. Burdon, personal communication; Singh and Hymowitz, Appendices I-D & -F).

RESEARCH ACCOMPLISHMENTS

Effects of environment and host maturation on rust development

Irrigation and precipitation. In Taiwan, rust is more severe in the spring and autumn seasons when temperatures are moderate

¹Mention of a trademark or proprietary product does not constitute a guarantee or warranty of the product by the U.S. Department of Agriculture and does not imply its approval to the exclusion of other products that may also be suitable.

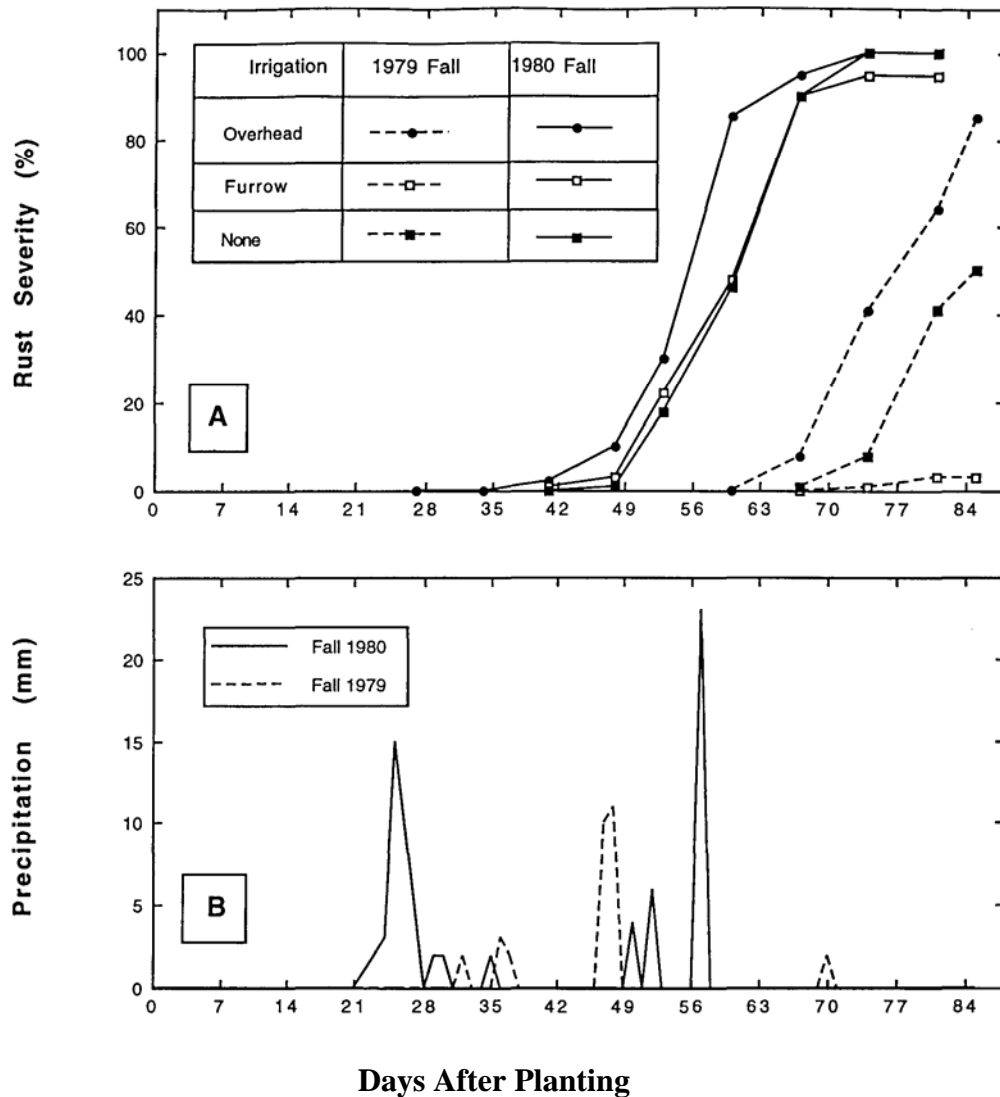


Figure 1. Rust severity in plots that were either overhead or furrow irrigated or nonirrigated (A) and corresponding precipitation (B) in two seasons. From Tschanz, 1982 (22).

and moisture is adequate. The summer season is more adverse to rust development as higher temperatures and heavy rainfalls prevail. Winter is too cool and dry. In a multi-season and- locational experiment, rust development varied according to prevailing rainfall patterns and rust developed most rapidly at locations where rainfall was more evenly distributed throughout the season and was slower in development at sites where rainfall occurred in uneven patterns (Figure 1)(22). In seasons with low rainfall, rust initiation was delayed, and the rate of rust development was reduced. Daily

precipitation promoted early and rapid rust development. Overhead irrigated plots had more rust than plants in plots that were furrow or nonirrigated. Precipitation was necessary for the early development of rust, even if soybeans were overhead irrigated. It was concluded that precipitation was more critical than the frequency and intensity of infection periods which were thought to intensify the rust epidemic.

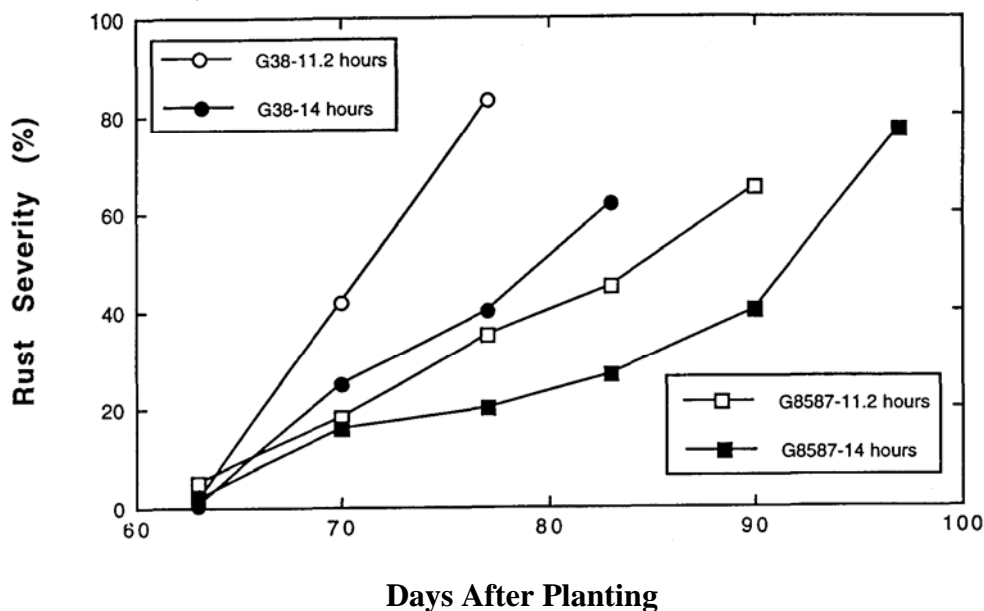


Figure 2. Rust severity of two soybean lines grown under an average day length of 11.2 hours (natural photoperiod) and under 14 hours of day length. From Tschanz and Tsai, 1982(22).

Soybean maturation. Three susceptible lines and one moderately resistant line (PI 230971, G8587) were monitored for rust development at AVRDC, Hualien, Pingtung, Taichung and Taitung. The apparent infection rates ranged from 0.1114 to 0.2197 and were not significantly different for lines within and over locations (25). Disease progress curves indicated that rust development on line G8587 was delayed compared to the other lines. Because of the delay in rust development, line G8587 was initially considered moderately resistant, and it appeared that this line may have a gene(s) for race-specific resistance that delayed the onset of the epidemic. However, since the apparent infection rates were similar to susceptible lines, it was evident that the delay in the epidemic was related to its longer maturity compared to the susceptible lines.

To determine the effect of maturity on soybean rust development, two lines were grown in the field under an average day length of 11.2 hours (10.7 to 11.9 hours)

and under a 14-hour-day length by extending the natural day length with tungsten lamps (23). Under longer day lengths, the growth stages R1 to R8 developed later for both lines and the rate of rust development was delayed and there was a highly significant ($P=0.01$) correlation between the rate of rust development to the number of days after planting (Figure 2).

Under field conditions, early maturing lines have rust severity earlier with higher rates of increase than later maturing lines. This interaction between host development and rust increase occurs in all field experiments and confounds rust ratings between lines. To evaluate and compare rust development on soybeans without correcting for the differences in host maturity can lead to erroneous conclusions about host resistance and environmental parameters related to disease development. A method for correcting differences in host maturity used the relative life time (RLT) as a time element from 0 to 100 (23). The time between planting and maturity was converted to a percentage of the soybean life cycle completed.

Table 1. Legume species that developed rust symptoms, and uredinia and urediniospores when inoculated with *Phakopsora pachyrhizi*. From Tschanz, 1982 (22).

<i>Alysicarpus glumaceus</i>	<i>Macroptilium atropurpureum</i> ^a
<i>Cajanus cajan</i> ^a	<i>Macrotyloma axillare</i> ^a
<i>Centrosema pubescens</i> ^a	<i>Medicago arborea</i>
<i>Crotalaria anagyroides</i> ^a	<i>Melilotus officinalis</i>
<i>Delonix regia</i>	<i>M. speciosus</i>
<i>Glycine canescens</i> ^a	<i>Mucuna cochinchinesis</i>
<i>G. clandestina</i> ^a	<i>Pachyrhizus erosus</i> ^a
<i>G. falcata</i> ^a	<i>Phaseolus lunatus</i> ^a
<i>G. max</i> ^a	<i>P. vulgaris</i> ^a
<i>G. tabacina</i> ^a	<i>Rhynchosia minima</i>
<i>G. tabacina</i> var. <i>latifolia</i>	<i>Sebania exaltata</i>
<i>G. wightii</i> ^a	<i>S. vesicaria</i>
<i>Lablab purpureus</i> ^a	<i>Trigonella foenum-graecum</i>
<i>Lotus Americana</i>	<i>Vicia dasycarpa</i>
<i>Lupinus hirsutus</i>	<i>Vigna unguiculata</i> ^a

^a Previously reported as an alternative host of *P. pachyrhizi*.

Table 2. Legume species that showed macroscopic symptoms after being inoculated with spores of *Phakopsora pachyrhizi*, but did not have uredinia and urediniospores associated with the symptoms. From Tschanz, 1982 (22.)

<i>Amorpha nana</i>	<i>M. orbicularis</i>
<i>Astragalus agrestis</i>	<i>Onobrychis viciaefolia</i>
<i>Crotalaria gorensis</i>	<i>Pueraria phaseoloides</i>
<i>Medicago cribreloides</i>	<i>Stizolobium hassjoo</i>
<i>M. intertexta</i>	

Isolate variability

Host range. A number of host range studies have been conducted. Of 98 legume species, 48 genera were not hosts (no symptoms), but species in seven genera had lesions without uredinia and 13 new hosts were reported in seven genera (Tables 1 & 2)(23). In addition, telia and teliospores were induced on a number of different legume species (36). Along with this, conditions

for uredinial development, unrediniospore production, and factors affecting leiospore formation on soybeans were documented (37).

Races. Three infection types have been described: 1) TAN=TAN lesions (0.4 mm² with 2 – 4 uredinia per lesion); 2) RB=reddish brown lesions (0.4 mm² with 0 – 2 uredinia per lesion); and 3) 0=absence of macroscopically visible signs or symptoms (7). Based on these infection

types, races of the pathogen have been described (7, 35). Yeh (35) identified three races among 50 single uredinial cultures using a set of five differential cultivars/lines. In addition, at least one race from Taiwan was reported to have three virulence genes (6, 9). In one study (2), 42 purified isolates were inoculated on Ankur, PI 200492, PI 230970, PI 230971, PI 239871A, PI 239871B, PI 459024 and PI 459025, TK-5, TN-4, and Wayne. Most isolates caused TAN-type lesions on at least seven of the lines and these isolates were classified into nine races. The data suggested that the predominant races are complex, and these races possess multiple virulence factors for compatibility on most of the lines. Other isolates from Taiwan were reported to cause rust on all known or suspected sources of specific resistance including PI 200492, PI 230970, PI 339871, PI 459025, and PI 462312 (28). The occurrence of multiple virulence genes in *P. pachyrhizi* is unusual because there are no soybean lines known to possess more than one specific resistance gene (28). The presence of multiple virulence genes in the pathogen population and the absence of multiple specific resistance genes in the host, could make techniques like gene rotation and pyramiding of specific resistance genes ineffective.

Host response

Identifying soybean resistance to rust has been a major objective at AVRDC as over 9,000 soybean accessions have been screened. Both rate-reducing and specific resistance along with tolerance occurs in the soybean germ plasm (23, 27). In addition, nearly 300 accession of wild perennial *Glycine* have been evaluated for resistance (11).

Specific rust resistance. Four independent dominant gene designations are: *Rpp1* (PI 200492), *Rpp2* (PI 230970), *Rpp3* (PI 462312), and *Rpp4* (PI 459025) (8, 14, 15, 16). Three other soybean lines, Tainung-4, PI459024 and PI 459025, and one *G. soja* line (PI 339871) are reported to have additional specific genes for resistance (15, 16). None of these single genes have been employed in

commercial cultivars because of the occurrence of races. Additional research indicated that PI 339871, PI 459024, PI 459025, and TK -5, Tainung -4 may also have single dominant genes for resistance (28). In addition, specific resistance has been reported in the wild *Glycine* spp. and some of these have been used as differential hosts for the identification of rust pathotypes (10).

Partial rust resistance. Lines with partial resistance or slow-rusting lines have been identified and characterized based on latent period and the number of uredinia per lesion (13, 25, 26). An example of partial resistance based on pustule counts in some lines that were selected at AVRDC is presented (Table 3; Hartman, unpublished data). A major impediment in developing lines with rate-reducing resistance has been how to evaluate lines from segregating populations or from accessions that have different maturities. Besides the physiological differences related to maturity, environmental conditions may vary as plants mature under different time periods. An evaluation method, which partially corrects for differences in host maturities, used the relative soybean life time (RLT) (26) and the logit transformation of rust severity to determine the level of rate-reducing resistance by comparing the slopes of the regression lines.

Tolerance to soybean rust. Tolerance is defined here as the relative yielding ability of plants under stress from rust. To evaluate the relative yield, comparisons between the same line planted in a fungicide-protected plot and nonfungicide-protected plot is used. Although it requires additional field space, tolerance is assessed once per season unlike obtaining data for disease progress curves, defoliation, and pustule counts for rate-reducing resistance. Based on this selection procedure, lines have been selected and screened in rust tolerance trials in Taiwan and Thailand (18, 24, 29). Based on percentage increase in yield when comparing lines, there appears to be advanced materials with good levels of tolerance or perhaps when fully

Table 3. Leaf area infected, defoliation, and total number of pustules per plant, per leaf, and at node 7 on 12 soybean lines inoculated with *Phakopsora pachyrhizi*.¹

Line	Leaf area infected %	Defoliation %	Total no. of pustules	Pustules/leaf	No. of pustules at node 7
AGS 129	45	28	1776	41	104
AGS 181	76	41	3849	130	87
AGS 302	43	20	2209	66	53
GC811118-8-4	54	29	2541	61	80
GC82345-20-2	66	34	5934	168	176
GC82349-6-1	53	41	2108	49	150
KS 8	64	36	2715	76	107
SRE B -15A	44	29	2272	70	83
SRE C-56A	25	24	803	23	25
SRE C-56E	31	24	709	19	29
SRE D-14C	35	16	2159	58	17
SRE D-14D	34	16	2100	54	51
Average	47	28	2431	68	78
LSD (P=0.05) ²	6	13	973	28	44

¹ Based on growth stage R5-R6

² LSD = least significant difference

characterized, with partial resistance. Yield losses in these tolerant lines were lower than the other high-yielding lines (Table 4). Similar trends occurred in these lines for 100-seed weight losses. Lines which were developed for their rust tolerance had the lowest levels of infected leaf area and were considered partially resistant based on pustule counts per leaf node (Table 3). Recently, along with the percentage increase in yield, stress tolerance index was adapted for evaluating rust tolerance using three dimensional plots to separate test materials into four groups. The X-Y plane (X=rust severity, Y=percentage yield) is divided into four segments by drawing intersecting lines at the midpoint of the X and Y axis. The Z axis indicates the level of stress tolerance that a line has in any one of the four groups. Use of three dimensional plots in separated and enabled selection of rust-tolerant high-yielding lines (5).

Wild species. Over a 3-year period, 294 accessions representing 12 perennial *Glycine* spp. were screened for resistance to *P. pachyrhizi* (11). Twenty-three percent of the 294 accessions were resistant, while 18% moderately resistant, and 58% susceptible. Fifty-nine and 40% of the *G. tabacina* (2n=80) accessions were resistant in two experiments. Resistance to *P. pachyrhizi* was located in accessions of *G. argyrea*, *G. canescens*, *G. latifolia*, *G. microphylla*, *G. clandestine*, and *G. tomentella*, but not in accessions of *G. arenaria*, *G. cyrtoloba*, *G. curvata*, and *G. tomentella* which has been crossed and back crossed with soybean (21) is being tested in Australia (Appendix I-D).

Rust development and yield losses

Disease progress curves. Monitoring rust epidemics has provided important information on how the disease develops. Various

Table 4. Yield and 100-seed weight in fungicide-protected plots and in rust-inoculated plots, and their losses on 12 soybean lines inoculated with *Phakopsora pachyrhizi*.

Line	Yield (kg/ha)			100-seed weight (g)		
	Fungicide-protected	Rust-inoculate	Loss (%)	Fungicide-protected	Rust-inoculated	Loss (%)
AGC 129	2800	837	70	16.1	7.5	53
AGC 181	2279	766	66	17.1	10.0	42
AGC 302	2400	1050	57	21.2	12.5	41
OC 81118-8-4	2816	471	83	17.3	6.2	64
GC 82345-20-2	2864	726	75	19.5	7.8	59
OC 82349-6-1	3440	837	76	22.5	14.3	36
KS 8	3498	528	85	29.8	11.1	63
SRE B-iSA	2386	1076	54	17.4	10.4	40
SRE C-56A	2567	1818	29	25.5	18.0	29
SRE C-56e	2656	1804	31	20.7	13.6	34
SRE D-14C	2804	1514	46	23.5	16.6	29
SRE D-14D	2605	1502	41	25.0	16.4	34
FLSD(P=0.05) ¹			9			8
FLSD(P=0.05) ²		214			2.0	
FLSD(P=0.05) ³		263			2.3	

¹Differences between main plot means.

²Differences between subplots within the same main plot.

³Differences between subplots with different main plots.

schemes for rating rust have included using a three digit notation (31), Horsfall-Barratt scale (25), and percentage leaf area infected (13).

In addition to leaf ratings, defoliation ratings are important. These are usually done by counting nodes with and without leaves often under rust and control plots. Several reports have used healthy tissue or green leaf area for comparison of treatments which compensates for the loss of leaves (13, 34). Assessments must be done over time during the growing season to be sufficient to analyze disease progress data. Most reports have used the disease or green leaf area progress data to develop areas under the curve to make statistical comparisons between treatments whether they be fungicide applications or tests of different cultivars/lines. Based primarily on dew period and temperature a simulation model for assessing soybean rust epidemics was developed (33).

Yield losses. Yield losses of up to 80% have been reported from experimental trials in many countries throughout Asia and in Australia. Heavily infected plants have fewer pods and lighter seed (13, 34). Marketable yields are even less because of poor seed quality (25).

Disease parameters to yield components. Several publications have addressed the issue of quantifying disease parameters like leaf area infected, defoliation, pustule counts, and area under curves to yield components. Yang *et al.* (34) regressed the relative area under the disease progress curve to seed growth rates, seed growth periods from R4 to R7 growth stage, and yield. Hartman *et al.* (13) regressed leaf area infected at growth stage R6 and the area under the disease progress curve to percentage yield of fungicide-protected plots

Percentage Yield of Fungicide Protected Plots

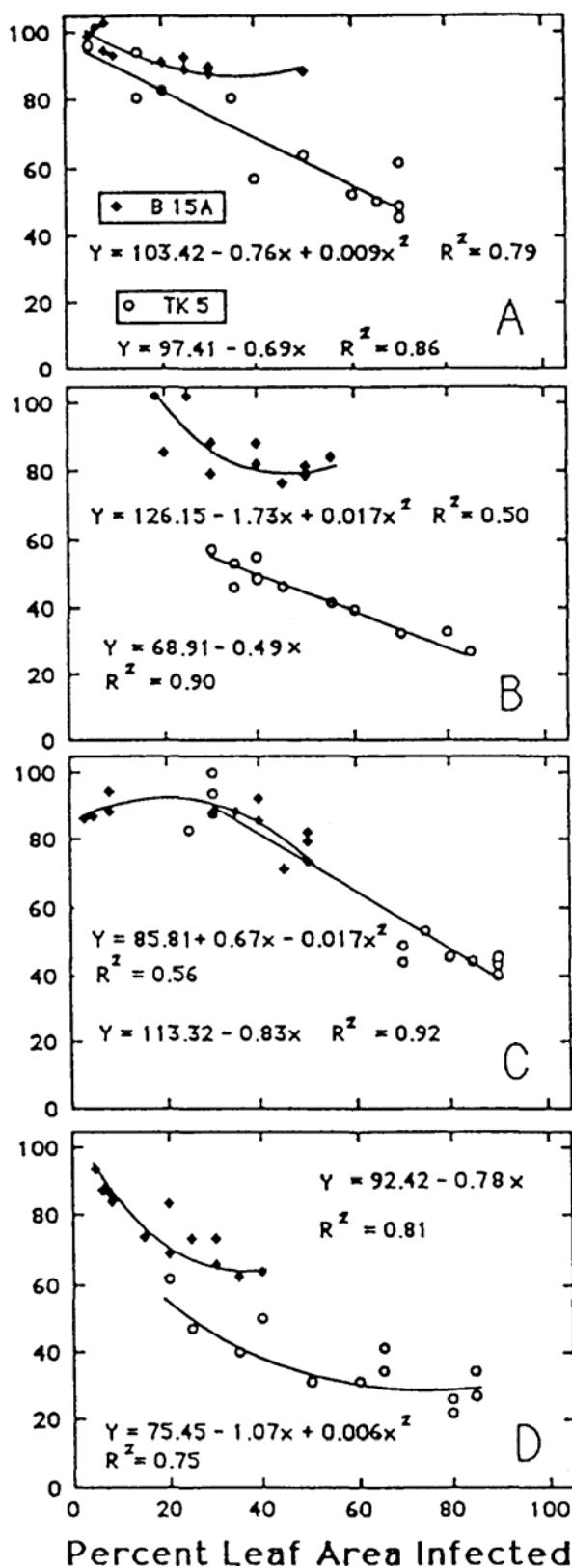


Figure 3. Percentage yield of fungicide-protected plants of two soy bean genotypes (B 15A and TK 5) on percent leaf area infected (A-D, represents trials 1-4, respectively). From Hartman *et al.*, 1991 (13).

(Figure 3). In these reports and in others, quantifying disease parameters to yield was effective and with additional information, this data has provided the basis for disease forecasting and yield loss models.

DISCUSSION

The epidemiology of soybean rust has been a major focus of AVRDC research for nearly 20 years. There have been a number of important discoveries related to the interaction of soybeans, *P. pachyrhizi*, and the environment. However, perplexing questions remain unanswered. For example, it is not known where the initial inoculum from season to season originates, what races predominate in an epidemic or what the number of virulence genes in any given population might be, and precisely what environmental parameters cause rust outbreaks. Since genetic control would have the most profound effect, future releases of soybean lines should have characterized resistance or tolerance to rust generated from techniques that better identify and quantify partial resistance and tolerance. The incorporation of resistance from the wild perennial *Glycine* spp. seems evident now that fertile crosses of *G. max* x *G. tomentella*, and advanced fertile backcross generations have been generated.

In addition, now that it is known that at least two species cause soybean rust (19), more information needs to be obtained on their distribution, host range, and genetics. With this information, more critical evaluations regarding the host range, geographic distribution, and their potential overlaps needs to be addressed carefully as future generations may have to contend with a mixture of populations and the potential for the emergence of new populations. Research to further characterize the pathological differences between the species and to determine if they have similar races, host ranges, and life cycles. In addition, the viability and germination of basidiospores needs further study to determine their role if any in the fungal life cycle.

Nonchemical control measures other than resistance or tolerance have not been very well

documented. Control practices like strip-cropping, irrigation patterns, use of biological control, avirulent strains, cross protection, and induced resistance have had limited success and/or have not been fully investigated. Although more is known about soybean rust now than 20 years ago, there are

still a number of basic and applied research questions to answer. At the present time, it remains to be seen which group or groups of researchers will be addressing the rust problem through the next 20 years.

LITERATURE CITED

1. Anonymous. 1992. Planning workshop of the establishment of the Asian component of a global network on tropical and subtropical soybeans. Chiang Mai, Thailand, March 2-7, 1992.
2. Asian Vegetable Research and Development Center. 1985. Annual report, AVRDC, 1983, Shanhua, Tainan, Taiwan, Republic of China (ROC).
3. Asian Vegetable Research and Development Center, 1987. Bibliography of Soybean Rust 1895-1986. 1987. AVRDC Publication No. 87-277. Shanhua, Tainan, Taiwan, ROC, 103p.
4. Asian Vegetable Research and Development Center. 1992. Annotated Bibliography of Soybean Rust (*Phakopsora pachyrhizi* Sydow). AVRDC Library Bibliography Series 4-1, Tropical Vegetable Information Service. AVRDC, Shanhua, Tainan, Taiwan, ROC Publ. No. 92-372, 160p.
5. Asian Vegetable Research and Development Center. 1993. Annual Report, AVRDC, 1992. AVRDC, Shanhua, Tainan, Taiwan, ROC.
6. Bromfield, K. R. 1981. Differential reaction of some soybean accessions to *Phakopsora pachyrhizi*. Soybean Rust Newsl. 4:2.
7. Bromfield, K. R. 1984. Soybean Rust. Monograph No. 11, APS Press, Inc., St. Paul, Minnesota, U.S.A., 65p.
8. Bromfield, K. R., and Hartwig, E. E. 1980. Resistance to soybean rust and mode of inheritance. Crop Sci. 20:254-255.
9. Bromfield, K. R., and Melching, J. 5. 1982. Sources of specific resistance to soybean rust. (Abstr.) Phytopathology 72:706.
10. Burdon, J. J., and Speer, S. S. 1984. A set of differential hosts for the identification of pathotypes of *Phakopsora pachyrhizi* Syd. Euphytica 33:891-896.
11. Hartman, G. L., Wang, T. C., and Hymowitz, T. 1992. Sources of resistance to soybean rust in perennial *Glycine* species. Plant Dis. 76: 396-399.
12. Hartman, G.L., Wang, T.C., and Shanmugasundaram, S. 1995. Soybean rust research: Progress and future prospects. In: World Soybean Res. Conf. V. (In press).
13. Hartman, G. L., Wang, T. C., and Tschanz, A. T. 1991. Soybean rust development and the quantitative relationship between rust severity and soybean yield. Plant Dis. 75:596-600.
14. Hartwig, E. E. 1986. Identification of a fourth major gene conferring resistance to soybean rust. Crop Sci. 26:1135-1136.
15. Hartwig, E. E., and Bromfield, K. R. 1983. Relationships among three genes conferring specific resistance to rust in soybeans. Crop Sci. 23:237-239.
16. McLean, R. J., and Byth, D. E. 1980. Inheritance of resistance to rust (*Phakopsora pachyrhizi*) in soybeans. Aust. J. Agric. Res. 31:951-956.
17. Nuntapunt, M., Surin, P., and Achavasmit, P. 1984. Evaluation of rate-reducing rust resistance and tolerance in advanced soybean lines. Journal of Agriculture Research and Extension (Thailand) 2:15-19.

18. Nuntapunt, M., Surin, P., Kejeetaveep, R., and Kajornmalee, V. 1994. Current research on soybean rust in Thailand. *J. Agric. Res. Extension (Thailand)* 2:805-812.
19. Ono, Y., Buritica, P., and Hennen, J. F. 1992. Delimitation of *Phakopsora*, *Physopella* and *Cerotelium* and their species on Leguminosae. *Mycol. Res.* 96:825-850.
20. Sinclair, J. B. 1989. Threats to production in the tropics: Red leaf blotch and leaf rust. *Plant Dis.* 73:604-606.
21. Singh, R. J., Kollipara, K. P., and Hymowitz, T. 1993. Backcross (BC2-BC4)-derived fertile plants from *Glycine max* and *Glycine tomentella* intersubgenetic hybrids. *Crop Sci.* 33:1002-1007.
22. Tschanz, A. T. 1982. Soybean rust epidemiology (final report). Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan, Republic of China, 157p.
23. Tschanz, A. T., and Tsai, B. Y. 1982. Effect of maturity on soybean rust development. *Soybean Rust Newsl.* 5:38-41.
24. Tschanz, A. T., and Tsai, M. C. 1983. Evidence of tolerance to soybean rust in soy beans. *Soybean Rust Newsl.* 6:28-31.
25. Tschanz, A. T., and Wang, T. C. 1980. Soybean rust development and apparent infection rates at five locations in Taiwan. *Prot. Ecol.* 2:247-250.
26. Tschanz, A. T., Sheng, W. S., and Tsai, B. Y. 1982. Development of soybean rust resistance in advanced breeding lines. *Soybean Rust Newsl.* 5:34-37.
27. Tschanz, A. T., Wang, T. C., and Hu, L. F. 1980. Epidemic development of soybean rust and a partial characterization of resistance to soybean rust. *Soybean Rust Newsl.* 3:35-41.
28. Tschanz, A. T., Wang, T. C., and Tsai, B. Y. 1986. Recent advances in soybean rust research at Asian Vegetable Research and Development Center. pp. 237-245. In: *Soybeans in Tropical and Subtropical Cropping Systems*. S. Shanmugasundaram and E. W. Sulzberger, Eds., Asian Vegetable Research and Development Center, Shanhua, Tainan, Taiwan.
29. Tschanz, A. T., Wang, T. C., Cheng, Y. H., Montha, N., and Chen, C. M. 1985. International screening trials for soybean rust tolerance. *Soybean Rust Newsl.* 7:22-25.
30. Wang, T. C., and Hartman, G. L. 1992. Epidemiology of soybean rust and breeding for host resistance. *Plant Prot. Bull.* 34:109-124.
31. Yang, C. Y. 1977. The IWGSR rust rating system. *Soybean Rust Newsl.* 1:4-6.
32. Yang, C. Y. 1991. Soybean rust caused by *Phakopsora pachyrhizi*. First Soybean Rust Workshop, Wuhan, Hubei, People's Republic of China, March 21-27, 1991.
33. Yang, X. B., Dowler, W. M., and Tschanz, A. T. 1991. A simulation model for assessing soybean rust epidemics. *J. Phytopathology* 133:187-200.
34. Yang, X. B., Tschanz, A. T., Dowler, W. M., and Wang, T. C. 1991. Development of yield loss models in relationships of components of soybean infected with *Phakopsora pachyrhizi*. *Phytopathology* 81:1420-1426.
35. Yeh, C. C. 1983. Physiological races of *Phakopsora pachyrhizi* in Taiwan. *J. Agric. Res. (China)* 32:69-74.
36. Yeh, C. C., Tschanz, A. T., and Sinclair, J. B. 1981. Induced teliospore formation by *Phakopsora pachyrhizi* on soybeans and other hosts. *Phytopathology* 71:1111-1112.
37. Yeh, C. C., Sinclair, J. B., and Tschanz, A. T. 1982. *Phakopsora pachyrhizi*: Uredial development, uredospore production, and factors affecting teliospore formation on soybeans. *Aust. J. Agric. Res.* 33:25-31.